

Fourier Analysis of Grooved Terrain on Ganymede from Galileo High Resolution Images.

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High resolution images of grooved terrain on Ganymede obtained by the Galileo SSI instrument show a much smaller spacing of ridges and grooves than suggested by Voyager imaging [1]. The spacing of Ganymede's grooves has been used as an important constraint on models of bright terrain formation, strain, lithospheric thickness, and thermal gradient [2,3]. Grimm and Squyres [2] applied Fourier analysis to brightness profiles extracted across Voyager images of groove sets, and found a mean spacing of ~8.4 km across Ganymede and ~6.5 km within Uruk Sulcus. This "Voyager" wavelength of deformation, which may reflect extensional necking of the lithosphere, is apparent in stereo imaging of the Galileo G1 high resolution target site, manifest as a correlation of brightness and long-wavelength elevation [Giese et al., Collins et al., this volume]. Direct viewing of stereo images of the Uruk Sulcus target site confirms that smaller-scale albedo striping correlates with topography, though not necessarily via a one-to-one relationship. Groove topography inferred from Galileo high resolution images is of nearly an order of magnitude smaller scale than inferred from Voyager data, and this topography likely results from normal faulting of Ganymede's brittle lithosphere [Pappalardo et al., this volume]. Quantification of the wavelength of these small-scale brightness variations through Fourier analysis permits intercomparison of the high resolution targets in order to document spatial and temporal variations that may reflect local differences in the grooved terrain formation process.

Technique. We follow the approach of [2] in applying Fourier analysis to the problem of groove spacing on Ganymede, with the view that brightness variations approximately correlate to topography. We apply a fast Fourier transform to profiles of distance versus DN extracted across lanes of grooved terrain, in order to obtain plots of spatial wave number (1/km) versus power and of the dominant wavelengths comprising terrain of the groove lane. Profiles were extracted from radiometrically calibrated and map reprojected Galileo images (Figure 1). Each photometric profile was constructed by averaging five adjacent one-pixel wide profiles along the groove lane strike. In order to eliminate the DC component in the profile, its mean value was subtracted. To reduce the "ripple" effect in the spectrum due to data truncation, a Hanning window has been applied on each profile. The total length of the Hanning window was chosen to be 1/3 the length of the profile, with the first half of the Hanning window used on the beginning of the profile and the second half of the Hanning window used on the end of the profile. Zero padding has also been applied before the transform to increase spatial wave number resolution. By defining the Fourier transform as:

$$F(k_x) = \int_{-\infty}^{\infty} f(x) e^{-j2\pi k_x x} dx$$

and the power spectrum of the profile is:

$$P(k_x) = |F(k_x)|^2$$

For each photometric profile, the averaged profile was plotted together with its power spectrum via spatial frequency and spatial wavelength. Each spectrum was searched for "significant" peaks, i.e. peaks above half of

the maximum value in the spectrum, as representative of the dominant wavelength(s) for the particular profile.

Results and discussion. Fourier analysis was performed on brightness profiles extracted across groove sets in the G1 Uruk Sulcus (75 m/pxl), G2 Nippur Sulcus, (100 m/pxl), and G2 Marius Regio Groove Lane (86 m/pxl) high resolution Galileo images. (For description and interpretations of the geology of these sites, see companion abstracts by Head et al. and Pappalardo et al. [this volume]). An example of the results is shown in Figure 2. Absolute power spectra are plotted instead of relative ones, allowing comparison of spectra for profiles extracted at different places along the same groove lane and/or comparison of sub-profiles. For the same groove lane, profiles chosen at different places along the groove lane strike can produce different spectrum features. The same sometimes is true even for sub-profiles of an individual profile. This may be caused by variation of the groove lane topography along strike and/or addition to the profile of other geological features (such as craters) encountered along-profile at different places along the groove lane strike. These differences also may indicate that the distribution of bright and dark materials and topography are not perfectly correlated. Close examination shows that many similar spectrum features are observed all along the groove lane strike. It is found that topographic wavelengths inferred visually from the images do not necessarily correspond to dominant wavelengths demonstrated by the Fourier analysis, as this technique makes the assumption that the grooved terrain brightness profiles are composed of multiple sinusoidal wavelengths.

Uruk Sulcus. Profiles were obtained across a prominent groove lane in the southwestern portion of the G1 Uruk Sulcus mosaic (unit PRT1 of Senske et al. [this volume]). Visually, the western side of this groove lane shows a larger topographic wavelength than the eastern side. Fourier analysis of brightness profiles across the groove lane shows dominant wavelengths of about 1.3 km and 1.9 km. Analysis of the eastern portion alone shows similar dominant wavelengths, plus an additional dominant wavelength at 0.7 km, the signal of which is apparently swamped in analysis of profiles across the entire groove lane. In the interpretation of this groove lane as a zone of domino-style extensional tilt blocks [Pappalardo et al., this volume], the shorter wavelength may have resulted from imbrication of large-scale tilt blocks into smaller blocks as extension and faulting proceeded.

Nippur Sulcus. Brightness profiles were obtained across groove sets in the G2 Nippur Sulcus mosaic, including those that comprise Philus Sulcus as well as Nippur Sulcus proper [Head et al., this volume]. Analysis of profiles across the constituent groove lanes of Philus Sulcus show dominant wavelengths of ~1.4 km and 2.4 km. These two wavelengths might reflect two scales of normal faulting, such as by incipient imbrication of horst-and-graben topography into domino-style blocks. Profiles across a ~20 km wide relatively smooth region near the southern boundary of Philus Sulcus shows peaks of very low relative power, confirming the visual impression that the surface is relatively featureless. Profiles across Nippur Sulcus proper show an extremely "impure" frequency spectrum, indicating a jumbled combination of many wavelengths of similar strength. This is consistent with the interpretation of a shear

component of deformation in Nippur Sulcus [Head et al., this volume], because shear is expected to produce much less regular structures than would imbrication by normal faulting alone.

Marius Regio Groove Lane. Profiles across a groove lane that cuts northern Marius Regio (Figure 1) shows dominant wavelengths at about 2.0 km and 3.4 km (Figure 2). The ~2.0 km wavelength is apparent in profiles obtained across the groove lane regardless of along-strike location, but the ~3.4 km wavelength varies in dominance along the groove lane's trend, as does a wavelength of ~10 to 11 km. Much of the material between the ridges and grooves of this groove lane appears relatively smooth [Head et al., this volume]; the along-trend variations in power along this groove lane may arise from variations in the degree of cryovolcanic flooding (or of reactivation of previously embayed features) along the length of the groove lane.

Summary. Fourier analysis was performed on brightness profiles across selected portions of three grooved terrain sites that were imaged at high resolution by Galileo. The profiles each reveal two or three dominant wavelengths that are interpreted as reflecting the regular spacing of structures produced by extensional faulting. Bright and dark lineaments of Ganymede's grooved terrain with measured wavelengths ~0.7 to 3.4 km are interpreted to reflect brittle deformation of Ganymede's near surface region. The presence of multiple dominant wavelengths suggests that faults of multiple scales have formed, perhaps through mixing of normal faulting styles (i.e. horst-and-graben and domino styles), and/or by imbrication of major fault blocks into smaller scale blocks. The presence of shear may suppress the signature of dominant wavelengths within grooved terrain, as may cryovolcanic resurfacing. Along-trend variations may be caused by changes in the groove lane topography along strike and/or imperfect correlation between topography and the distribution of bright and dark materials. Stereo imaging of the Uruk Sulcus high resolution target indicates that the "Voyager" scale of tectonic deformation is real, and this scale of deformation is suggested by a ~10 km dominant wavelength in brightness profiles extracted from the Marius Regio groove lane images. Further analyses will be performed on these and additional Galileo high resolution images, along with comparison to groove wavelengths derived from Voyager images, Galileo stereo data, and Galileo photoclinometric data. These studies will allow for improved characterization of the spatial and temporal variations in dominant wavelengths across Ganymede's grooved terrain, a better understanding of the correlation of these brightness variations to topography, and additional analyses of the local-scale variations which may affect them.

References. [1] Belton, M.J.S., et al., *Science* 274, 377 (1996). [2] Grimm, R.E., and S.W. Squyres, *JGR* 90, 2013 (1985). [3] Fink, J.H., and R.C. Fletcher, *PGPI*, NASA TM-84211, 51 (1981); Golombek, M.P., *JGR* 87, PLPSC 13, A77 (1982); Herrick, D.L., and D.J. Stevenson, *Icarus*, 85, 191 (1990).

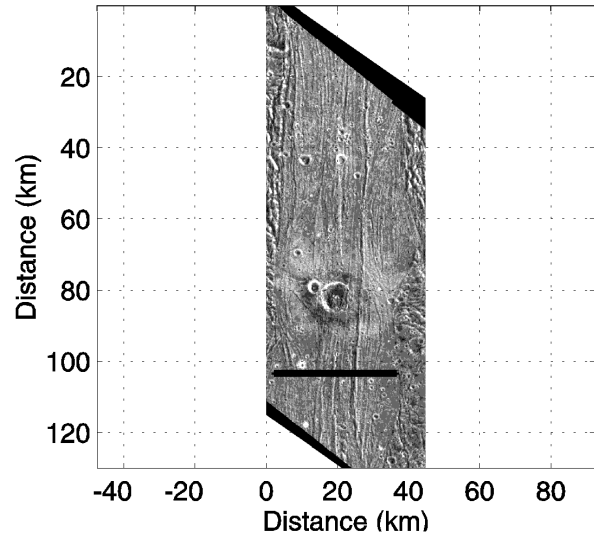


Figure 1. Example profile across the Marius Regio groove lane.

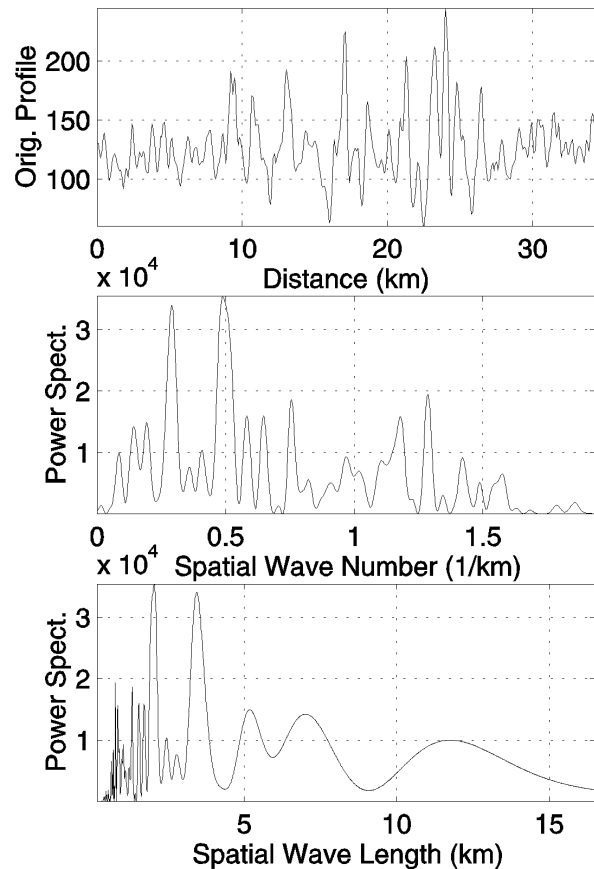


Figure 2. Brightness profile (top), spatial wave number (center), and spatial wavelength (bottom) for sample a profile across the Marius Regio groove lane.